MUON CRYOSYSTEM DESIGN NOTE 19

SUBSYSTEM: [ ] CCM [ ] CVM [X] Cryoplant

TITLE: Refrigerator Operating Procedures

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OPERATING PROCEDURES

2.0 Cooldown of the Helium Refrigerator

The purpose of the refrigerator is to provide liquid helium to CCM and CVM. This procedure will put the refrigerator into operation filling the buffer dewar, S-1.

System Status:

a) The compressor system is operational and stable, with no flow into the heat exchangers.

b) The refrigerator, dewar and magnet system have been pumped and purged, all u-tubes are installed and all insulating vacuums evacuated to 25 microns or lower.

c) The liquid nitrogen supply system is operational.

d) ODH alarm system is operational.

2.1 Refrigerator Pressurization

The refrigerator will be pressurized slowly to avoid shocking the system. Flow will be circulated to check for contaminants if the system is warm.

a) Look over the entire helium system for unplugged pumpouts, or any abnormal situation.

b) Open exchanger I inlet valve EVX1 100%. Open return valves MV-200-H and PV-LPR.

c) All control loops should be disabled and all other control valves closed.

d) Open pressurizing valve MV-104-H.

e) When the system is pressurized, PDIS-PHPS is less than 10 psid, open supply valve PV-HPS.

f) Close pressurizing valve MV-104-H.

g) If the system is cold following a brief depressurization proceed with the appropriate cooldown procedure.

h) Open bypass valve MV-101-H to achieve a flow of 30 grams/second or more at FXHP. Monitor the moisture and nitrogen content of the helium for fifteen minutes. If both are below ten PPM proceed with cooldown. If not discuss with engineering and Lab A personnel.

i) Close MV-101-H.

2.2 Refrigerator Cooldown above $90^{o}K$

The refrigerator will be cooled down using liquid nitrogen from storage. All control loops are disabled from the previous shutdown.

a) Check that all control loops are disabled with the valves closed.

b) Fill exchanger EX-I with liquid nitrogen. Enable loop 2 (EVXLN) to maintain the level.

c) If the dewar S-1 is above $15^{o}K$, open EVDEWH 100%. If it is colder open EVXBY 100%. Open EVXJT 20%. Flow will enter through the exchangers and the dewar until their temperatures approach $80^{o}K$.

d) Flow can be increased through EVXJT. Do not increase the flow beyond the capacity of EX-I to cool it.

e) Enable loop 17 (EVX2) to control RXLP at $250^{o}K$.

2.3 Refrigerator Cooldown below $90^{o}K$

This procedure starts the expansion engines. It may be started when RDEW is below $90^{o}K$. Before proceeding to the next steps, visually inspect both the wet and dry engines to ensure proper and safe operation.

a) Dry Engine: Before starting the dry engine cool it to below 150 K.

   1) Prop open the intake and exhaust valves on the engine.

   2) Push the engine purge button, sending some gas through the engine. When RDEOUT reads below $150^{o}K$ cooldown is complete.

   3) Release the purge button.

   4) Remove the propping mechanism.

b) Start the engine and run at minimum speed until RDEOUT is below $50^{o}K$.

c) After the engine has run for at least 15 minutes enable loop 3, switching the engine speed to automatic.

d) Disable loop 17 and enable loop 1, (EVX2) starting normal flow through exchanger II.

e) Enable loop 0, (EVX1) which will begin reducing flow through exchanger 1.

f) Adjust EVXJT until inlet flow (FXHP) is between 20 and 30 grams per second.

g) Before starting the wet engine cool it to below 150^{O}K.

   1) Prop open the intake and exhaust valves on the engine.

   2) Push the engine purge button, sending some flow through the engine. When RWEOUT reads below 150^{O}K cooldown is complete.

   3) Release the purge button.

   4) Remove the propping mechanism.

h) Start the engine and run at minimum speed until RWEOUT is below 20^{O}K, for at least 15 minutes.

i) Close EVXJT.

j) Slowly increase the wet engine speed.

k) When the wet engine inlet temperature reaches 6^{O}K, enable loop 5 (EVXBY). This will maintain the engine inlet temperature.

l) Liquid helium should begin to collect in the dewar. When the level is 10% or higher, enable loops 4 (SPWE) and 15 (SPWE).

m) Gradually close EVDEW until PDEW is about 8 psig. Enable loop 12 (EVDEW).

3.0 Nitrogen Circulation System

The nitrogen circulation system cools the radiation shields and heat intercepts in CCM, CVM and the transfer lines. Normally one pump sends liquid from separator S-2, through the magnets and back to S-2. S-2 is filled from the outside storage vessel.

3.1 Filling Phase Separator S-2

The purpose of this procedure is to cooldown and fill S-2 without cooling the pumps.

a) The LN_2 storage pressure should be between 15 and 25 psig.

b) Close pump suction valves MV-471-N and MV-481-N.

c) Open manual supply valves MV-418-N and MV-460-N.

d) Switch S-2 level control, HS-S2 to automatic. Valve PV-S2 will open and will cycle to maintain a level in the separator.

e) To stop filling S-2 switch HS-S2 off.

3.2 Cooldown and Start a Pump

The purpose of this procedure is to prepare a pump for operation. It assumes neither pump is operating.

a) Put separator S-2 level in automatic operation.

b) Close CVM nitrogen supply valve MV-436-N unless the magnet is already cold.

c) Close CCM nitrogen supply valve MV-591-N unless the magnet is already cold.

d) Open pump purge supply valves MV-476-N and MV-486-N. Purge pressure should be 2 psig. The purge gas should be on whether the pump is running or not.

e) Isolate the pump not being used. To isolate P-1 close MV-471-N, MV-478-N, and MV-466-N. To isolate P-2 close MV-481-N, MV-488-N and MV-467-N.

f) Fill the pump to be started. For P-1 open suction valve MV-471-N, and cooldown valve MV-466-N. For P-2 open valves MV-481-N and MV-467-N. Check the time.

g) Make sure that nitrogen leaving the pump will have a place to go. If the magnets are both closed off, open recycle valve MV-491-N fully. If the magnets are cold and the nitrogen has been off less than 2 hours, the recycle and balancing valves should be left as is.

h) Open the pump discharge valve. For P-1 it is MV-478-N. For P-2 it is MV-488-N.

i) Between ten and thirty minutes after the pump suction valve was opened the pump may be started. When it is started watch for unusual noise, leakage, pump siezure, etc. If something goes wrong stop the pump immediately. The pump boost should be stable and at least 30 psid within 5 seconds after start. Press the pump start button.

j) Close the cooldown valve, MV-466-N or MV-467-N.

3.3 Switch from one Pump to the other

This procedure will stop one pump and start the other. This will avoid upsetting the magnet cooling.

a) Cooldown the warm pump. Open the suction valve, MV-471-N for P-1 or MV-481-N for P-2, and the cooldown valve, MV-466-N for P-1 or MV-467-N for P-2. Check the time.

b) Open the pump discharge valve, MV-478-N for P-1 or MV-488-N for P-2.

c) Between ten and thirty minutes after the pump suction valve was opened the pump may be started. When it starts watch for unusual noise, leakage, pump siezure, etc. If something goes wrong stop the pump immediately. The pump boost should be stable and at least 30 psid within five seconds after start.

d) Stop the running pump. Start the other pump.

e) Close the cooldown valve on the running pump and open the cooldown valve on the stopped pump. This allows nitrogen vapor from the pump to return to the separator.

f) Close the suction and discharge valves on the stopped pump.

3.4 Pump Shutdown

This procedure stops a pump and vents the nitrogen in it.

a) Press the stop button.

b) Open the cooldown valve, MV-466-N for P-1 or MV-467-N for P-2.

c) Close the pump suction and discharge block valves.

d) Open recycle valve MV-491-N.

3.5 Strainers

Both CCM and CVM are equipped with single Y-strainers and dual fine mesh strainers. The fine mesh strainers can be switched and derimed as follows:

a) The strainers should be changed if the differential pressure exceeds 3 psid.

b) Close all deriming valves. They are the small Worcester valves in the assembly. Their tag numbers on CCM are MV-654-N, MV-655-N, MV-656-N, MV-657-N. ON CVM they are MV-095-N, MV-096-N, MV-097-N, MV-098-N.

c) Open the vent on the warm strainer. This is either MV-655-N, MV-657-N, MV-095-N or MV-096-N.

d) Open the outlet valve on the warm strainer. This is either MV-651-N, MV-653-N, MV-092-N or MV-094-N. Check the time.

e) Ten minutes after opening the outlet valve, close the vent valve and open the liquid nitrogen inlet valve on the new strainer.

f) Close the inlet and outlet valves on the old strainer and open it's vent.

g) To speed warmup and purge the strainer open the gas supply valve, either MV-654-N, MV-656-N, MV-095-N or MV-097-N.

4.0 CCM Refrigeration

The CCM refrigeration system includes a pool boiling magnet, a nitrogen cooled radiation shield and a support column adjustment system.

4.1 CCM Cooldown Above 80

Helium gas is cooled to about 80 K in exchanger EX-8 and fed to the CCM coil cryostat and helium reservoir. As the magnet cools the radiation shield is gradually cooled and when necessary the support columns are moved with the hydraulic system.

a) Switch on the liquid nitrogen to heat exchanger EX-8. Valve PVX8LN will open and close to maintain the level in the exchanger.

b) If the refrigerator is not operating, pressurize the high pressure piping and check the helium contaminant content as described in Procedure 2.1.

c) Prepare for cooldown by opening all valves in the cooldown flow path except throttling valve MV-522-H as listed below. The flow path is through EX-8, the magnet coil, EX-22 and back to compressor suction.

   Close throttling valve MV-522-H.
   Open return valve PVLPR.
   Open return block valve MV-579-H.
   Open flowmeter bypass valve MV-572-H.
   Insert the CCM helium supply and return extension tubes into the cups.
   Open inlet block valve MV-513-H.

d) Begin flow by opening MV-522-H to establish a flow of 2.4 grams per second as indicated by FX8HP. The flow will be gradually increased as the outlet temperature drops. The cooldown rate must be limited to 2.5 K per hour, as measured by coil resistance. A table of resistance vs. temperature is on the following page. Record the coil resistance every two hours.

CCM COIL RESISTANCE vs TEMPERATURE

Upper Coil		Lower Coil	
Resistance	Temp. °K	Resistance	Temp. °K
1	50	1	50
2	57	2	57
3	69	3	64
4	71	4	71
5	77	5	77
6	85	6	83
7	92	7	90
8	99	8	97
9	106	9	103
10	112	10	110
11	119	11	117
12	127	12	123
13	133	13	130
14	140	14	137
15	147	15	143
16	153	16	150
17	161	17	156
18	171	18	163
19	174	19	170
20	181	20	176
21	188	21	183
22	195	22	190
23	202	23	196
24	209	24	203
25	216	25	209
26	223	26	216
27	230	27	223
28	236	28	229
29	243	29	236
30	250	30	243
31	257	31	249
32	264	32	256
33	271	33	263
34	278	34	269
35	285	35	276
36	292	36	283
37	299	37	289
38	306	38	296
39	312	39	302
40	318	40	309

The flow may be increased as outlet temperature RCCMCD decreases. Use the following as a guide to achieve the cooldown rate.

When RCCMCD is below 250 K increase flow to 2.8 grams/second.

When it is below 200 K increase flow to 3.5 gram/second.

When it is below 150 K increase flow to 5.0 gram/second.

When it is below 120 K increase flow to 10 gram/second.

When it is below 100 K increase flow to 14 grams/second.

e) The shield should be cooled down concurrently with the magnet coil. Close nitrogen balancing valve MV-610-N and start the nitrogen circulation system as described in Procedure 3.2.

f) Open the liquid nitrogen supply valve MV-591-N, and the fine strainer block valves.

g) The average temperature of the nitrogen shield should be kept within 10 ^{o}K of the lower coil temperature. The average temperature of the lower coil nitrogen shield is determined by averaging TE #5 and TE #7. The temperature may be read on the thermocouple readout channels #5 and #7. Adjust balancing valve MV-610-N to maintain the above temperature tolerance.

h) CCM column position requirements. Make sure that all the silicon bronze lock down bolts are removed. Initially all the linear resistors should read zero mils. If not adjust until all of them read zero. Adjust to zero mils and record the readings indicated by all of the dial indicators. Initially record both the linear resistors and dial indicators every two hours. Check to see that the motion indicated by the linear resistors agrees with the dial indicators, if not find the cause and correct it. Then calculate the average of the 12 dial indicator readings for the lower coil columns and for the upper coil columns. Next calculate the average of the 4 coil position dial indicator readings for the lower coil and for the upper coil. When the difference between the average lower coil column readings and the average lower coil position readings are greater than 40 mils, similarly for the difference between the average upper coil column readings and average upper coil position readings, it is necessary to bump the columns with the hydraulic system.

Do not keep the hydraulic pressure on the columns for more then 5 seconds. Only push in the set of columns upper and/or lower columns that do not meet the above requirements. Also check to see that no column is more then 150 mils out of position as compared to its other 11 neighbors. If it is, try using the hydraulic system to individually push or pull this column into better agreement with its neighbors. The column could also be brought into better agreement using its silicon bronze lock down bolts. Do not try to lock the columns into a particular position using the hydraulics or the bolts. If the above requirements can not be met call in a CCM cryo expert. As the magnet cools down the time between readings can be increased and as long as there is good agreement between the dial indicators and the linear resistors the requirement for reading the dial indicators can be eliminated.

i) Record the following data every four hours. Data sheets are provided at the end of this procedure.

1) Flow rate at FX8HP.
2) Temperature out at RCCMCD.
3) Temperature out of exchanger 8 - RX8OUT.
4) Resistance of both the upper and lower coils (chart recorder and DVM entries in log).
5) Temperature of heat shields (4 thermocouples).
6) Temperature of intercept of power chimney (1 thermocouple).
7) Temperature of N_2 shield on the electrical interconnecting tube (1 thermocouple).
8) 7 room temperature strain gage readings. (Optional).
9) 4 cryogenic temperature strain gage readings. (Optional).
10) 8 side-load indicator readings.
11) 24 column sliding action indicator readings.

j) Continue cooldown until the temperature leaving the magnet at RCCMCD is below 90 K for over 24 hours.

4.2 CCM Cooldown Below 85 K

This portion of the cooldown is done by supplying liquid helium to the magnet. The helium is returned to the compressor. The maximum flow rate is limited by refrigerator capacity.

a) If the refrigerator is not running, start it and fill dewar S-1 per Procedure 2.0.

b) Close meter bypass valve MV-572-H.

c) The nitrogen cooled shield should be completely cooled down with balancing valve MV-610-N fully open and liquid nitrogen temperature at RCCMLN below 81°K.

d) Slowly open CCM inlet valve EVCCM. Control loop 9 should remain disabled. Flow should be about 0.8 grams per second as read on rotameter FI-578-H. The flow may be increased up to the refrigerator capacity. The level in dewar S-1 must not drop below 40% as indicated on LLDEW. A rapidly dropping level indicates that too much helium is being used.

e) When a helium level is established in CCM, open valve EVCCMOUT. Close return valve MV-579-H. This will return helium gas to the refrigerator.

f) When the level approaches the normal setting, enable loop 9 (EVCCM). The level will remain constant and ready for operation.

4.3 CCM Warmup

a) Normally the helium gas will be stored at the 15 foot Bubble Chamber during warmup. Open return valve MV-579-H.

5.0 CVM Refrigeration

The CVM refrigeration system includes a 450 liter dewar, circulation pumps and long tubular conductors.

5.1 CVM Cooldown Above 83 K

The maximum cooldown rate is 1.2 K per hour. There is no minimum. Since the magnet acts as a counterflow heat exchanger the helium flow must be kept high to reduce the temperature difference between the outside and the center of the coils.

a) If the refrigerator is operating, reduce the engine speed so that the refrigerator flow rate is below 40 grams/second.

b) If the refrigerator is not operating, pressurize and check the contaminent content as described in Section 2.1.

c) Prepare for cooldown by opening all valves in the cooldown flow path except throttling valve MV-507-H. The flow path is through EX-5, EX-6, the magnet coil, pump dewar, EX-5 and back to compressor suction. Make sure EVX6LN is closed.

   Open return valve PVLPR.
   Open EX5 return valve MV-511-H.
   Open block valve MV-526-H.
   Turn pump dewar selector valve MV-007-H to the cooldown position.
   Open block valve MV-525-H.
   Close lead flow valve MV-021-H.

d) Begin flow by slowly opening MV-507-H. Open it slowly so that supply pressure PXHP does not drop below 250 psig.

e) Increase flow until it is between 45 and 50 grams per second on FX5HP. As the flow is increased check pressures in the pump dewar. PCVM should not exceed 20 psig.

f) After helium flow is established begin liquid nitrogen flow. Every action to increase cooling must be done very slowly. The maximum cooldown rate is 1.2 ^{o}K per hour. This means EX-6 outlet temperature RX6HP must never be more than ten degrees below RX5LP, EX-5 inlet temperature. Disable loop 7 and close EVX6LN. Open nitrogen block valve MV-537-N.

g) Set the temperature difference (RX5LP-RX6WP) at 2 ^{o}K and enable loop 7 (EVX6LN).

h) Record the flow FX5HP and the temperatures RX5LP, RX6LP, and the five CLTS elements in the CVM every two hours. Do not use the Apple plotting program for this recording.

i) Every two hours after starting cooldown step g, raise the set point in 2 K steps until a difference of 10 K is reached. Continue to monitor the magnet temperatures. When in doubt about magnet safety close EVX6LN. Cooldown can be stopped without damage. If the magnet cooldown rate exceeds 1.2 K per hour reduce the temperature difference accordingly.

j) Check the flow rate every eight hours. It must be kept between 45 and 50 grams per second. Adjust valve MV-507-H as necessary.

k) When the magnet temperature is between 175 and 200 K cooldown the intercept and radiation shield with liquid nitrogen circulation system. Close nitrogen balancing valve MV-497-N. Open the nitrogen supply valves MV-436-N, MV-435-N, MV-492-N and the strainer block valves.

l) If necessary start one of the circulation pumps per Section 3.2.

m) Slowly open the nitrogen balancing valve MV-497-N. A steady temperature decrease of about 5 degrees per minute should begin in the nitrogen return line. When the temperature at RCVMLN is below 100 K the valve may be fully opened.

n) When the average magnet temperature is below 83 K stop the cooldown by closing helium supply valve MV-507-H and nitrogen valve EVX6LN.

o) The magnet may be held at this temperature indefinitely with the nitrogen circulation system only.

5.2 CVM Cooldown Below 83 K

This phase of the cooldown is limited by refrigerator capacity. It assumes the refrigerator is in normal operation.

a) Close EX-5 block valves MV-511-H and MV-507-H.

b) Open valve EVCVMOUT in control loop 14. This loop is always disabled. Open dewar S-1 outlet valve MV-318-H.

c) Slowly open CVM inlet valve EVCVM. Loop 8 should remain disabled. Flow through the magnet should be gradually increased to about ten grams per second, as indicated on FX7LP. Use exchanger E-7 outlet temperature RX7LPOUT to initially monitor cooldown of the transfer line. FX7LP will be inaccurate for temperatures above 8 K.

d) Slowly open CVM inlet valve EVCVM. Loop 8 should remain disabled. EVCVM will be used to manually adjust the cooldown rate. The maximum flow will be about ten grams per second as indicated on FX7LP. Limit the flow by the following constraints.

1) The temperature leaving EX-7, RX7LPOUT, must be below 7.5 K. During cooldown of the heat exchanger this temperature should be watched to avoid adding heat to the refrigerator too quickly. Flow meter FX7LP will be inaccurate at temperatures above 8 K.

2) The wet engine inlet temperature must stay below 6 K. It is indicated on RWEIN.

3) The level in dewar S-1 must not drop below 40%, as indicated by LLDEW. A rapidly dropping level indicates too much heat into the system.

4) The temperature difference RX7LPIN - RX7HPOUT must not exceed 10 K.

e) Once steady flow is established recheck the conditions at least every four hours. Adjust EVCVM as necessary to maintain the proper conditions.

f) Begin lead flow when RX7LPIN is below 50 K. Set loop 11 (EVCVML). At 0.3 grams/second and enable it. Balance the two lead flows with valves MV-025-H and MV-028-H if necessary.

g) When the CVM reaches 4.5 K, liquid will begin accumulating in the magnet and the CVM pump dewar. Normally operation will continue in the cooldown mode until the normal operating level is reached.

5.3 CVM Holding Ready to Operate

The procedure should be used when the magnet is to be kept cold ready to operate. It may be done subsequent to cooldown or normal energized operation.

a) If the cooldown operation from Procedure 5.2 is being completed, switch fill valve EVCVM to automatic level control by enabling control loop 8. Do not enable this loop unless the actual level is within 20% of the set point.

b) If the magnet has been operating with helium circulation, switch to holding mode. Stop the circulation pumps and switch pump dewar selector valve to the cooldown position. The pump dewar level control should already be enabled.

5.4 CVM Warmup

a) There are several ways to add heat to the magnet. Normally the helium will be stored at the 15 foot Bubble Chamber. During warmup, open dewar vent valve MV-005-H to return helium to storage.

b) If the compressors are not operating, open pump dewar vent valve MV-002-H and vent it to the atmosphere.

6.0 Taking an Engine Off-Line

System status: Refrigerator running in normal operating mode.

Necessary items:

a) Two men minimum, one who has participated in cold U-tube removal. Three people more easily handle U-tubes and fittings.

b) Leather gauntlet type gloves.

c) Face shields.

d) Pipe wrench and torch.

e) Personal ODH monitors.

6.1 U-Tube Removal

a) Shut off the helium flow. Disable control loops 0 and 1 and close EVX1 and EVX2.

b) Disable loop 8 and close EVCM.

c) Disable loop 9 and close EVCCM.

d) Shut down both engines by pushing STOP button.

e) Blow down the high pressure side of the heat exchanger. Disable loop 5 and open EVXBY. Disable loop No. 6 and open EVXJT. Both sides of the heat exchanger should now float at suction pressure. Check the pressure on PX2HP and PX2LP.

f) Check suction pressure on PX2LP. If it is below 1.5 psig have it raised at Lab B or by opening bypass valve MV-101-H. Do not proceed unless it is below 4 psig.

g) With someone at each end of the inlet U-tube equipped with safety gloves and face shields, loosen the two Goddard fittings while holding U-tube down.

h) Avoiding hesitations or delays, simultaneously lift both ends of the inlet U-tubes above the ball of the ball valves.

i) Quickly close both ball valves.

j) Screw the protective caps onto both Goddard fittings.

k) Repeat steps e and h on the exhaust U-tube.

l) If the engine is to remain off for an extended period of time or if electrical work is to be done, disconnect electric power to the engine.

6.2 Refrigerator Operation Without the Wet Engine

The refrigerator may run at reduced capacity without the wet engine.

a) Close EVXBY.

b) Open EVX1 20% to pressurize the system.

c) Run the dry engine normally per Section 2.

d) When the dry engine outlet temperature falls below 16 K on RDEOUT, slowly open EVXJT. When the valve box inlet temperature RVBIN approaches 5.5 K, enable control loop 6 (EVXJT).

7.0 Off-Line Engine Warm-Up and Repair

System status: The engine is isolated from system and is cold.

1) Isolate engine from system using Procedure 6 "Taking an Engine Off-Line".

2) Connect an engine warm-up (helium) bottle or alternative helium source such as MV-116-H and a heater (optional), and tubing as shown in Figure 1.

3) Prop open the engine intake and exhaust valve(s).

4) Prop open the air actuated shut-off valve.

5) Set the regulator, Victor model VTS 450 B-580, to 10 psig; adjust pressure as needed to allow steady stream of purge gas.

6) Set the heater to 150 ^{o}F.

7) Start single pass flow by opening the intake and exhaust ball valve(s).

8) Flow gas until condensation no longer forms on exhaust valve.

9) Check that all relief and gage lines are above condensation temperature by opening 1/4" valves on each line and observing the temperature of gas.

10) Remove the propping mechanisms from intake, exhaust and shut-off valves.

11) The engine can now be worked on without condensation forming. Follow repair procedures in the maintenance manual.

FERMILAB
ENGINEERING NOTE

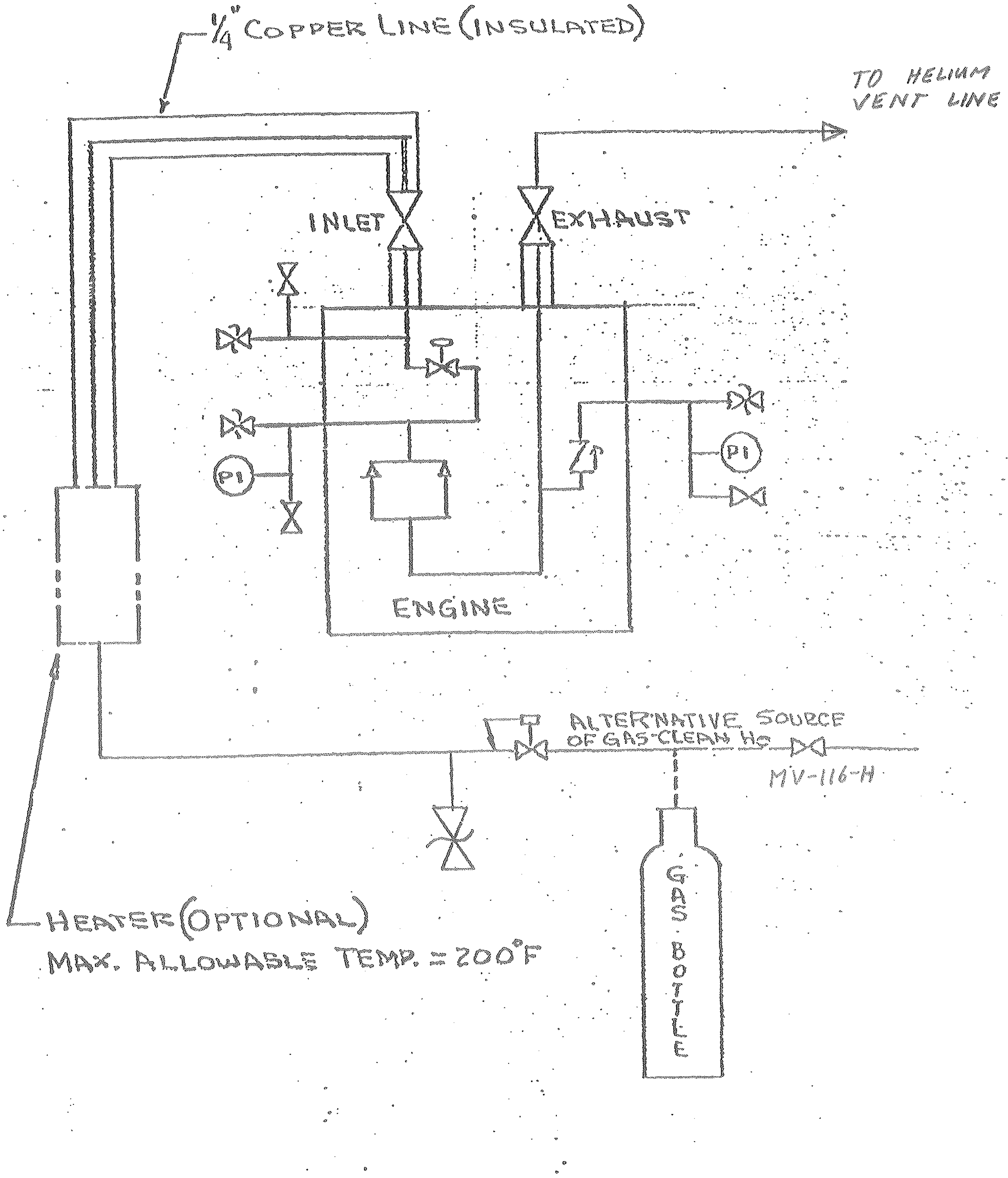
SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: FIG #1 - ENGINE WARM-UP FLOW DIAGRAM

NAME: E. STANEK

DATE: 2/83

REVISION DATE: 4/2/86 RLS



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8.0 Routine Maintenance on Engines

System status: Refrigerator cold and operational.

This procedure should be performed once per week. It should be done quickly to avoid dumping the magnets.

1) Enter the current operating conditions into the engine log book (pressures, temperatures, speed, hp, hours, date, time, initials and comments).

2) Read the cryostat vacuum and enter it into the log book.

3) Switch the engine controller to LOCAL and push the "STOP" button.

4) Lubricate the following areas per maintenance schedule using elapsed time on hour meter.

   CTI Wet and Dry Engines

Component	Lubricant
Cam Followers	Molub-Alloy
Main Bearings	Molub-Alloy
Jackshaft Bearings	Molub-Alloy
Wrist-Pin Bearings	Molub-Alloy
Crank-Pin Bearings	Molub-Alloy
Crosshead Guides	Lidok
Valve-Arm Bushing	Light Machine Oil

5. Check the tension on the motor/generator belt.

6. Set the intake and exhaust tappet clearances to the following specifications using CTI manual procedures.

   Cold Engines

	CTI Wet	CTI Dry
Intake	0.010	0.010
Exhaust	0.010	0.010

   Warm Engines

	CTI Wet	CTI Dry
Intake	0.025	0.025
Exhaust	0.025	0.025

7. Replace and secure the protective cover.

8. Switch the engine controller to the REMOTE position.

9. Engine should start and be controlled remotely. Verify proper operation. Take a complete set of readings when temperatures have stabilized.

9.0 Putting an Engine On-Line

System status: Refrigerator is cold. The engine has been dehydrated, pumped and purged.

Necessary items:

a) Two men minimum, one who has participated in cold U-tube insertion. Three people more easily handle U-tubes and fittings.

b) Leather gauntlet type gloves.

c) Face shields.

d) Pipe wrench and torch.

e) Personal ODH monitor.

f) Necessary props, tubing, He supply, etc.

9.1 Install Inlet U-Tube

a) Unscrew protective caps on all four Goddard fittings for the engine U-tubes.

b) Prop open the intake and exhaust valves.

c) Connect 1/4" tubing from a helium gas bottle or MV-116-H to engine intake pressure gauge vent valve.

d) Crack open the two engine bayonet ball valves.

e) Take a light purge through the engine by throttling open the engine intake pressure gauge vent valve.

f) Push the engine purge button to purge the intake bayonet.

g) Following a 10-20 second purge, close the intake bayonet ball valve.

h) Release the purge button.

i) Allow light purge to continue through the exhaust bayonet for one minute. Purge the engine exhaust gauge line and inlet relief line during this time for 5-10 seconds, using vent valves.

j) Close the exhaust bayonet ball valve and engine intake pressure gauge vent valve simultaneously.

k) Remove the propping mechanisms from the intake and exhaust valves.

l) Remove the 1/4" helium supply line from engine, making sure vent valves are closed.

m) Disable control loops 0 and 1 and close EVX1 and EVX2.

n) Blow down the high pressure side of the heat exchangers. Disable control loop 5 and open EVXBY. Disable control loop 6 and open EVXJT. Both sides of the heat exchanger should float at suction pressure. Check the pressure on PX2HP and PX2LP.

o) Disable loop 8 and close EVCVM. Disable loop 9 and close EVCCM.

p) Check the suction pressure on PX2LP if it is below 1.5 psig, have it raised at Lab B or by opening bypass valve MV-101-H. If it is above 4 psig lower it before proceeding.

q) Verify that each end of both U-tubes have O-rings. Use dehydrated U-tubes.

r) Install the inlet U-tube first. With someone at each end of the U-tube equipped with safety gloves and face shields. Crack open the ball valve opposite the engine, allowing a light purge to flow through the U-tube.

s) After a 5-10 second purge, open both ball valves fully and quickly insert the end of the U-tube stingers.

t) Avoiding hesitation or delays, simultaneously lower both ends of the U-tube.

u) Tighten both Goddard fittings while holding U-tube down.

9.2 Install the Exhaust U-Tube and Purge

a) Check that the engine controller electrical breaker is in the ON position.

b) Connect a 1/2" diameter copper line between the engine exhaust bayonet and the helium vent line.

c) Open EVX1.

d) Crack open the engine exhaust bayonet valve.

e) Turn engine speed controller to the minimum (counter clockwise) position.

f) Start the engine.

g) Increase speed to 250 RPM and operate for 2 minutes.

NOTE: Adjust the exhaust bayonet ball valve such that the engine exhaust pressure gauge is less than 10 psig.

h) Stop engine by pushing the STOP button.

i) Close the exhaust bayonet ball valve.

j) Remove the 1/2" diameter copper line from the exhaust bayonet.

k) Verify that both ends of the U-tube have O-rings. Use dehydrated U-tubes.

l) With someone at each end of the U-tube equipped with safety gloves and face shields, crack open the ball valve opposite the engine, allowing a light purge to flow through the U-tube.

m) After a 5-10 second purge, open both ball valves fully and quickly insert the end of the U-tube stingers.

n) Avoiding hesitation or delays, simultaneously lower both ends of the U-tube.

o) Tighten both Goddard fittings while holding U-tube down.

p) Start engine per procedure 2.3.

10.0 On-Line CTI Valve Replacement (Cold State)

System status: Refrigerator cold and operating.

Necessary items:

a) Pre-assembled valve assembly.

b) Leather gauntlet gloves.

c) Wrenches and tools.

PROCEDURE

a) Disable control loops 0 and 1 and close EVX1 and EVX2.

b) Switch the engine controller to LOCAL and push the stop button. Engine may already be off due to power reversal.

c) Activate the emergency brake.

d) Switch the expander electrical circuit breaker to the off position. This is an important step since it disables the expander high pressure supply valve from opening.

e) Bleed down the high pressure by opening the intake valve(s) and venting through the inlet pressure gauge vent valve (MV-162-H, Wet: MV-132-H, Dry). For the wet engine, open bypass valve EVXBY to reduce engine exhaust to compressor suction pressure.

f) Disassemble necessary components per the expander maintenance manual without exposing cold sections of the engine. Verify that helium is not leaking into the cylinders through valves.

g) Removal of components which expose cold sections of the engine must be done quickly.

While wearing protective gloves, remove the existing valve and replace immediately with a replacement valve. Avoid getting grease on valve spacers. Replacement time between sealed conditions should be less than three seconds. If replacement time is longer than three seconds, engine is probably contaminated. In this case follow procedures:

6 - "Taking an engine off-line"
7 - "Offline engine warm up"
8 - "Putting an engine on-line"

to be sure the engine is properly decontaminated before resuming operation.

h) Reassemble items from Step F.

i) Switch the expander electrical circuit breaker to the ON position.

j) Reset the emergency brake.

k) Switch the engine controller to REMOTE.

l) Open EVX1 to pressurize the system, if necessary.

m) Enable control loops 0 and 1.

n) Start the engine; verify that engine is being controlled properly.

o) Verify that the valve change cured the problem.

11.0 On-Line Expander Shutoff Valve Replacement (Cold State)

System status: Refrigerator cold and operational.

Necessary items:

1) Leather gauntlet gloves.

2) Replacement shut off valve.

PROCEDURE

a) Disable control loops 0 (EVX1) and 1 (EVX2).

b) Slowly close EVX1 and EVX2.

c) Allow the high pressure to reduce to 25 psig as read on PX2HP.

d) Switch the engine controller to LOCAL and push the STOP button. Engines may already be off due to power reversal.

e) Bleed down the high pressure side of expander through the intake pressure gauge vent valve (MV-132-H dry, MV-162-H wet). For the wet engine, open bypass EVXBY to reduce the exhaust pressure to compressor suction pressure.

f) Remove the valve actuator.

g) While wearing protective gloves, remove valve stem assembly and immediately replace with a spare assembly. Replacement time between sealed conditions should be less than a few seconds. If replacement time is longer than three seconds, engine is probably contaminated. In this case follow procedures:

   6 - "Taking an engine off-line"
   7 - "Offline engine warmup"
   8 - "Putting an engine on-line"

   to be sure the engine is properly decontaminated before resuming operation.

h) Replace the valve actuator.

i) Open EVX1 to pressurize the system.

j) Enable control loops 0 (EVX1) and 1 (EVX2).

k) Verify that the new valve seals.

l) Start the engine.

m) Switch engine control to remote.

12.0 Procedure for Deriming Refrigerator Heat Exchanger

System status: System is cold and operational when plug develops.

Plugging of the heat exchangers is caused by contamination (water, oil, nitrogen or other gases) freezing solid in the flow passages. This solid mass decreases the flow area which increases the pressure drop - the first sign of a problem. If pressure drops are monitored closely, a plug can usually be detected during its formation, thereby, decreasing the chances of a solid plug forming, i.e., one which stops all flow. Plugging in the shell side is very rare, therefore, the following procedures will concentrate on removing plugs in the tube side.

The procedure for warming a particular section of the refrigerator and purging out the contaminants varies with location. The following steps are common to all procedures.

12.1 Isolate High Pressure Flow to Heat Exchangers and Disable Control Loops

a) Disable control loops 0 and 1.

b) Slowly CLOSE EVX1 and EVX2.

c) Switch both engine controllers to LOCAL and push the stop buttons. The engines may already be off due to power reversal.

d) Bleed down the system to suction pressure. Disable control loops 5 and 6 and open EVXBY and EVXJT.

e) Disable the following control loops.

   1. Disable control loop 2 and close EVXLN.

   2. Disable control loop 8 and close EVCVM.

   3. Disable control loop 9 and close EVCCM.

   4. Disable control loop 10 and open EVCCML.

   5. Disable control loop 11 and open EVCVML.

   6. Disable control loop 12 and close EVDEW.

f) Open dewar vent valve MV-320-H.

g) Close dewar inlet valve MV-313-H.

12.2 Isolation of Clean Parts of System

Depending upon the extent of the warm up process and the suspected contaminated areas the amount of the system which can be isolated will vary. This procedure assumes that the system was cold and operational when the plug developed.

a) Typically, the dry engine will catch contaminates which will result in poor operation, i.e. high pressure drop, valve leakage etc. It is assumed that the dry engine will be taken off line and decontaminated, the extent of which will depend on the severity of the problem. See Procedures 6 and 7 for details.

b) In very few instances will the helium dewar S-1 be affected by contamination. For most cases it can be isolated with the following steps:

   Close MV-313-H
   Disable loop 12 and close EVDEW
   Open vent valve MV-320-H.

c) If the wet engine and valve box are to be warmed for decontamination dewar S-1 should be isolated from the refrigerator by pulling the U-tube that connects the valve box to the dewar. By pulling the wet engine U-tubes, the cold box, valve box and engines can now be worked on independently.

d) If it is not necessary to work on the wet engine, the cold box can be isolated from the rest of the system by pulling the U-tube between the end box and the valve box. The valve box will now float with suction pressure.

12.3 Heating and Purging Flow Discussion

Decide whether the gas used during the purge step of the cleanup will be saved or vented to the atmosphere. This should be determined based on severity of the plug, best guess as to nature of the contamination and availability of a liquid nitrogen purifier.

The criteria used to determine when the purging should be stopped i.e., when all the contaminants have been removed, is a function of the amount of detection equipment available. The purge should continue until all traces of contaminants are out of the system. Hygrometer readings should not measure any water content. The arc-cell should show nitrogen concentrations as low as the storage level. Temperatures of the component that is being warmed must be above that needed to melt the contaminant. Frost on the exhaust purge line is a good indication that the temperature of the component still is below that needed to melt an ice plug.

The following procedures are for warming of the entire heat exchanger package starting with the plugged exchanger and continuing to the warm end.

It is possible through manipulation of the block and bleed panel valves to warm any one individual exchanger but this is seldom desirable since most contamination will be frozen out in the first two exchangers and it would be beneficial to purge this from the system on any warm up.

In each of these procedures, it is assumed that the purging of dirty gas will be vented to the atmosphere. If the exchangers are warmed to room temperature, they can be pumped and purged using clean helium gas, to facilitate clean up.

The warming of the tube side is accomplished by blowing gas through the shell. Gas is kept flowing through the tube side to purge the contaminants from the system and prevents migration towards the colder end of the heat exchangers.

12.4 Deriming Heat Exchanger I

a) Shut off liquid nitrogen flow: Disable control loop 2 and close EVXLN.

b) All block and bleed manifold valves should be closed.

c) Blow out any remaining liquid nitrogen. Purge through the nitrogen shell of heat exchanger I by blowing warm helium gas through MV-112-N and exhausting out the normal nitrogen exhaust line. Continue until the exchanger is above the desired temperature.

d) Flow through tube side.

   Open PVHPS per procedure 2.1, if necessary
   Open MV-124-H
   Close MV-203-H
   Open MV-204-H
   Open MV-107-H
   Throttle MV-123-H to achieve steady flow of purging gas.

e) When the decontamination is complete:

   Close MV-107-H
   Close MV-204-H
   Open MV-203-H
   Close MV-124-H
   Close MV-123-H

12.5 Deriming Heat Exchanger II and IIA

a) Flow through the tube side

Open MV-108-H
Open MV-106-H
Close MV-203-H
Open MV-204-H
Open MV-124-H
Throttle MV-123-H to achieve steady flow of purging gas.

b) Flow through the shell side

Open MV-223-H
Throttle MV-224-H to achieve maximum flow through shell without raising pressure at PX2LP above 5 psig.

NOTE: 1) Flow through shell side is clean and is returned to suction of compressor. Verify that compressor inventory control loops are stable; if not, cut back on MV-224-H.

c) When decontamination is complete:

Close MV-224-H
Close MV-223-H
Close MV-204-H
Close MV-123-H
Close MV-124-H
Close MV-106-H
Open MV-203-H

d) Follow start up procedure 2 to bring heat exchangers back on line.

12.6 Deriming Heat Exchanger III

a) Flow through the tube side

Open MV-106-H
Open MV-107-H
Close MV-203-H
Open MV-204-H
Open MV-134-H
Throttle MV-133-H to achieve steady flow of purging gas.

b) Flow through the shell side

Open MV-233-H
Throttle MV-234-H to achieve maximum flow through shell without raising pressure at PX2LP above 5 psig.

NOTE: 1) Flow through shell side is clean and is returned to suction of compressor. Verify that compressor inventory control loops are stable; if not, cut back on MV-234-H.

2) Shell side gas can be taken back to the compressor using MV-223-H and MV-225, thus eliminating the need to warm up the shell of Hex II, only if not venting tube side gas.

c) When decontamination is completed:

Close MV-204-H
Close MV-106-H
Close MV-107-H
Open MV-203-H
Close MV-234-H
Close MV-233-H
Close MV-133-H
Close MV-134-H

d) Follow the startup procedure to bring heat exchangers back on line.

12.7 Deriming Heat Exchanger IV

a) Flow through the tube side:

Open MV-106-H
Open MV-107-H
Close MV-203-H
Open MV-204-H
Open MV-154-H
Throttle MV-153-H to achieve steady flow of purging gas.

b) Flow through shell side:

Open MV-253-H
Throttle MV-254-H to achieve maximum flow through shell without raising pressure (PT-255-H) above 25 psig.

NOTE: 1) Flow through shell side is clean and is returned to suction compressor. Verify that the compressor inventory control loops are stable; if not, cut back on MV-254-H.

2) Shell side gas can be taken back to the compressor suction using MV-233-H and MV-235-H, thus eliminating the need to warm up the shell of Hex II and Hex III, only if not venting tube side gas.

c) When decontamination is complete:

Close MV-204-H
Open MV-203-H
Close MV-254-H
Close MV-253-H
Close MV-153-H
Close MV-154-H
Close MV-106-H
Close MV-107-H

d) Follow the start up procedure to bring heat exchangers back on line.